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GROWTH RATES OF HOST AND PATHOGEN AS FACTORS DETERMINING THE SEVERITY OF PREEMERGENCE DAMPING-OFF [1]

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INTRODUCTION

Severity of preemergence damping-off is determined by several factors, among which mass of inoculum, host susceptibility, temperature, and soil moisture are usually the most important. Many workers have studied the effect of temperature upon seedling diseases. Two outstanding papers are those by Dickson (*3*),[2] who demonstrated that *Gibberella saubinetii* (Mont.) Sacc. produced severe infection upon corn at low temperatures and upon wheat at high temperatures, and by Jones, Johnson, and Dickson (*9*), who summarized the results of a number of temperature studies. The latter writers raised the question whether the dominant influence of temperature was through the pathogen or through the host. They concluded that with *G. saubinetii* the effect must be through the host. The relative susceptibility of the host at different temperatures was explained by Dickson and Holbert (*4*) as due to chemical differences within the host. At about the time that Dickson (*3*) was making his experiments with *G. saubinetii* Richards (*20*) tested the pathogenicity of *Rhizoctonia solani* Kühn upon several hosts and from these investigations Jones, Johnson, and Dickson (*9, p. 59*) concluded that the "relation of temperature to parasitism with *Rhizoctonia* is a fixed character of the fungus" and that "neither the nature of the host nor its normal temperature relations materially influence the temperature range for the parasitic action of this fungus."

In the present studies the pathogenicity of several damping-off fungi has been tested on different hosts in constant-temperature chambers with uniform soil moisture. Upon the same host several specific organisms show different temperature ranges for infection. Likewise a single organism may have different optimum temperature ranges for infection of different hosts. Usually the relative severity of infection at different temperatures did not correspond closely to the growth rate of either the host or the pathogen. As a rule, however, the percent of seedlings emerging from infested soil at different temperatures agreed closely with the ratio between the coefficient of velocity (*11*) of emergence and the growth rate of the organism at the same temperatures (*12, 13*). Since this relation held for several combinations of hosts and pathogens, conceivably it might have a general

[1] Received for publication October 4, 1946.

[2] Italic numbers in parentheses refer to Literature Cited, p. 178.

application. Utilization of this principle would aid in the selection of planting periods that permit the seedlings to escape infection from some seedling pathogens and to avoid severe infection from others.

PROCEDURE

All tests were conducted in a series of eight thermostatically controlled temperature chambers at 4° to 35° C. Temperature variations were less than 1° in all chambers except the 4° one, where readings as high as 6° or 7° were sometimes recorded during the long periods required for germination.

DETERMINATION OF SEEDLING EMERGENCE RATES

For studying seedling emergence Yolo fine sandy loam first was pasteurized at 80° to 90° (*21*) and then was moistened to field capacity [3] (16 percent) with a spray of distilled water while the soil revolved in an electrically driven cement mixer. Plantings were made in the manner described by Doneen and MacGillivray (*5*). Ten No. 2 tin cans with friction tops and each containing 300 gm. of this soil were placed in each temperature chamber along with a reserve of soil for covering the seeds. The following day, after the soil in each chamber had reached a constant temperature, 10 seeds of the host to be tested were placed in each can and covered with 100 gm. of soil from the same chamber. The cans were then topped and immediately replaced in the constant-temperature chamber. Each day the lids were removed so that germination might be observed and so that gases might not accumulate and inhibit germination.

The emerged seedlings were counted daily during the emergence period and the coefficient of velocity of emergence at each temperature was calculated by the Kotowski (*11*) formula:

$$\frac{\text{Total emergence at end of period}}{\text{Sum of (each daily emergence increase} \times \text{days since planting)}} \times 100 = \text{C. V. E.}$$

The rate of emergence can also be expressed by the mean emergence period (*14*), calculated in the same way as the coefficient of velocity except that the sum of the products is divided by the total emergence at the end of the trial. Or the coefficient of velocity divided into 100 is equal to the mean emergence period expressed in days. For example, a coefficient of velocity of 4 indicates a mean emergence period of 25 days, whereas one of 20 represents a mean emergence period of 5 days. The results in table 1 show that, relatively speaking, spinach is favored by low or moderate temperatures, whereas watermelons emerge rapidly only at high temperatures, a difference that is well known. Garden peas, wheat, and sugar beets emerge fairly rapidly at low temperatures, but are intermediate between the low- and high-temperature crops mentioned above.

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[3] The writer is indebted to Dr. L. D. Doneen, of the Irrigation Division, University of California, Davis, for adjusting the soil moisture and for making all moisture determinations.

TABLE 1.—*Relation of temperature to emergence rate of seeds planted in pasteurized soil*

Temperature (° C.)	Coefficient of velocity of emergence [1]				
	Spinach	Wheat	Garden peas	Sugar beets	Watermelons
4	4.2	2.6	2.4	1.6	0
8	7.1	5.1	4.6	4.6	0
12	10.3	10.1	8.8	8.4	0
16	15.7	13.2	10.5	10.8	3.6
20	17.6	15.2	12.3	16.1	8.5
25	19.5	20.9	16.8	23.4	21.1
30	15.4	22.9	15.1	23.8	28.7
35	None	None	None	21.9	33.0

[1] See definition, p. 162.

DETERMINATION OF FUNGUS GROWTH RATES

Some of the difficulties involved in measuring fungus growth rates have been reported by Fawcett (*6*). The time factor is important but it is difficult to secure comparable rates without selecting more or less arbitrary periods for the different temperatures. Measurements on potato-dextrose agar were secured by placing a 2-mm. disk of agar, from near the periphery of a young fungus colony, as inoculum in the center of preincubated agar plates. At each temperature, radial growth was measured at intervals of 24 hours or less until the colony approached the edge of the petri dish, and the average growth in millimeters per 24-hour period was calculated. Near the optimum temperature, the maximum growth permitted by the dish was sometimes reached within 48 hours, whereas at low temperatures several weeks were required by some organisms.

TABLE 2.—*Growth rates of 4 damping-off pathogens*

Temperature (°C.)	*Pythium ultimum* on—		*Rhizoctonia solani* on solid medium	*Aphanomyces cochlioides* on solid medium	*Phoma betae* on solid medium
	Solid medium	Liquid medium			
	Millimeters per 24 hours	*Milligrams per 24 hours*	*Millimeters per 24 hours*	*Millimeters per 24 hours*	*Millimeters per 24 hours*
4	0.8	1.0	0	0	0.7
8	4.1	3.6	.1	.6	1.3
12	10.9	12.2	3.1	2.1	2.4
16	17.2	17.2	6.9	3.9	3.0
20	22.4	22.2	13.4	5.4	4.3
25	29.1	19.4	19.0	7.6	4.7
30	27.5	15.6	19.6	8.8	3.6
35	6.8	8.0	9.7	4.6	.4
40	0	0	1.0	----------	----------

As table 2 shows, the optimum temperature range for *Pythium ultimum* Trow appeared to fall between 25° and 30° C. This corresponds to the results obtained by Middleton (*17*), who found the highest growth rate at 28°, but it is considerably lower than the optimum of 32° reported by Harter and Whitney (*7*) for an isolate of this species from sweetpotato.

Since the mycelial growth of *Pythium ultimum* was less dense at 30° and 35° C. than at 20° or 25°, the growth rate was also determined by dry-weight yield in a liquid medium. Flasks of potato-dextrose broth were inoculated in triplicate at each temperature. Again the

length of the incubation period had to be adjusted according to the rapidity of growth. At the end of the incubation period the fungus colony was separated from the medium in a filter and then washed and dried. The growth rate was measured by the average weight of the dried colony in milligrams per 24 hours of incubation. As is shown by the results in table 2, the growth rates of *P. ultimum* on solid and in liquid medium were similar at temperatures of 4° to 20°, but growth at 25° and 30° was considerably less in the liquid medium. Most writers agree that measurement of fungus mass is more reliable than radial growth; and the growth rates in liquid medium are used in all comparisons with *P. ultimum*. Since, however, other fungi such as *Rhizoctonia solani*, *Phoma betae* Frank, and *Aphanomyces cochlioides* Drechs. did not show the same difference in density of colony, only the radial growth rates are used in this paper.

EFFECT OF TEMPERATURE ON PREEMERGENCE DAMPING-OFF

Infested soils were prepared by spraying a suspension of fungus mycelium into the pasteurized soil at the time the moisture content was adjusted. Young colonies of the fungus on agar media were suspended in distilled water by mixing with a Waring blender. With coenocytic fungi such as *Pythium ultimum* and *Aphanomyces cochlioides* excessive mixing in the blender resulted in some loss of viability. The degree of infestation of the soil was governed by the amount of fungus inoculum added and by the time of incubation before planting. In each test the identity of the casual organism was confirmed by pure culture isolation from infected seedlings or by microscopic examination of infected seedlings placed in water culture.

PYTHIUM INFECTION OF SPINACH

To determine the severity of preemergence damping-off for each combination of host and pathogen, germination trials were conducted in pasteurized soil and in soil infested with a specific organism. For example, Prickly Winter spinach seed planted in pasteurized soil at various temperatures germinated at rates indicated by the coefficient of velocity shown in table 3. The percentage of seedlings that

TABLE 3.—*Relation of growth rates of spinach and Pythium ultimum to emergence in infested soil*

Temperature (° C.)	Emergence of spinach, coefficient of velocity [1]	Growth rate of *P. ultimum*	Ratio of growth rates,[2] host to pathogen	Emergence in—	
				Pythium soil	Pasteurized soil
		Milligrams per day		*Percent*	*Percent*
4	4.2	1.0	4.20	95	95
8	7.1	3.6	1.97	12	96
12	10.3	12.2	.84	1	96
16	15.7	17.2	.91	0	95
20	17.6	22.2	.79	5	97
25	19.5	19.4	1.00	16	96
30	15.4	15.6	.99	13	23
35	0	8.0	----------	0	0

[1] See definition, above.

[2] Ratio = $\frac{\text{Emergence rate of spinach (coefficient of velocity).}}{\text{Growth rate of } P.\ ultimum \text{ (milligrams per day)}}$

emerged at each temperature indicates that in the absence of pathogenic organisms spinach germinated about equally well between 4° and 25° C., but very poorly at 30° or above.

In *Pythium*-infested soil, however, preemergence damping-off was severe at all temperatures above 4° C., but especially so between 12° and 20° (table 3). The ratio of growth rate of the host to that of the pathogen (column 4), bears a close relation to the emergence of spinach in *Pythium*-infested soil (fig. 1), with no preemergence infection at 4° where the ratio is above 4.0 but with severe infection where the ratio drops to 1.0 or below.

RHIZOCTONIA INFECTION OF SPINACH

The ratio of the growth rate of spinach (table 4) to that of *Rhizoctonia solani* shows that at 4° and 8° C. the host grew relatively faster than the fungus. At these temperatures there was no evidence of

TABLE 4.—*Relation of growth rates of spinach seedlings and Rhizoctonia solani to emergence in infested soil*

Temperature (° C.)	Emergence of spinach, coefficient of velocity	Growth rate of *R. solani*	Ratio of growth rates,[1] host to pathogen	Emergence of—			
				Seed lot A in—		Seed lot B in—	
				Rhizoctonia soil	Pasteurized soil	Rhizoctonia soil	Pasteurized soil
		Millimeters per day		*Percent*	*Percent*	*Percent*	*Percent*
4	4.2	0	∞	86	73	(2)	95
8	7.1	.1	71.00	81	77	(2)	96
12	10.3	3.1	3.32	65	81	93	96
16	15.7	6.9	2.28	35	77	82	95
20	17.6	13.4	1.31	1	75	34	97
25	19.5	19.0	1.03	0	77	1	96
30	15.4	19.7	.78	0	11	0	23
35	0	9.7	--------	0	0	0	0

[1] Ratio = $\frac{\text{Emergence rate of spinach (coefficient of velocity).}}{\text{Growth rate of } R.\ solani \text{ (millimeters per day)}}$

[2] Not tested.

preemergence damping-off. As the temperature increased, the ratio of host growth rate to pathogen growth rate decreased, and a corresponding increase in the severity of infection took place with both seed lots A and B (fig. 2,*A* and *B*). Infection was less severe, however, upon seed lot B with high germination than upon seed lot A which showed lower viability.

Kotowski (*11*) found that the germination of spinach seed decreased with each increase in temperature from 5° to 30° C. In the present trials there were no differences in the percent of emergence of spinach seed planted in pasteurized soil between 4° and 25°; although emergence was reduced considerably at 30°. Since Kotowski's results resemble those observed in infested soil, perhaps his sand medium contained a mild infestation of damping-off pathogens, such as *Rhizoctonia solani*.

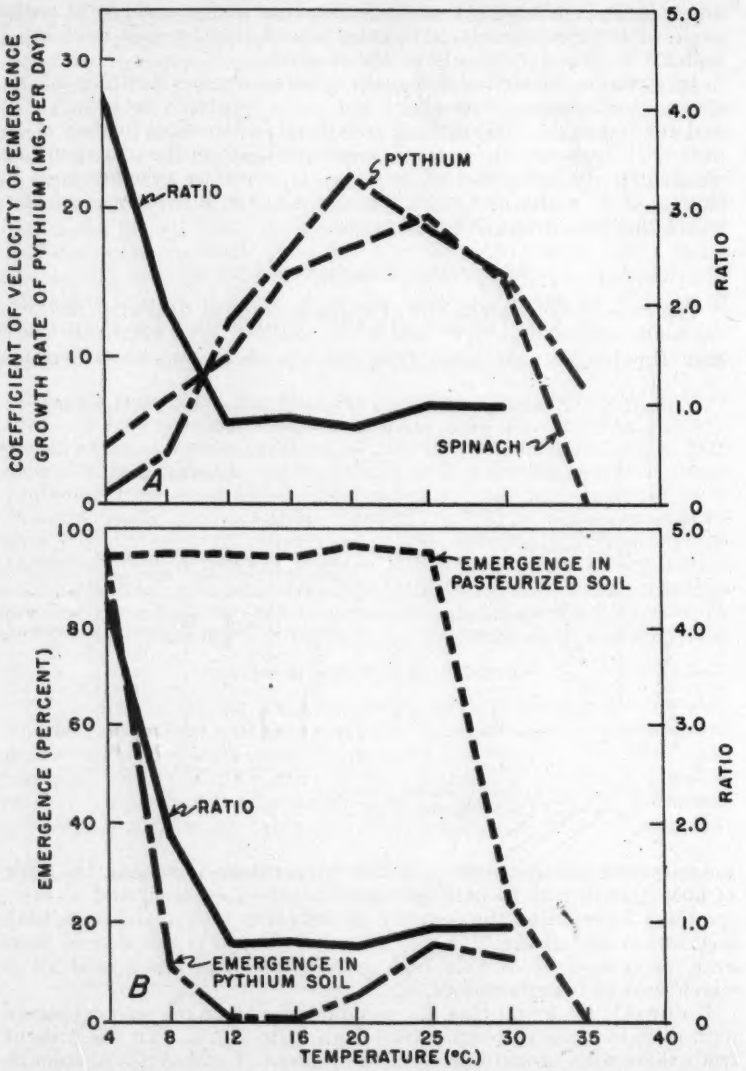

FIGURE 1.—*A*, Coefficient of velocity of emergence of spinach in pasteurized soil, growth rate of *Pythium ultimum* in liquid medium, and ratio of emergence rates of spinach to growth rate of *Pythium; B*, percent emergence of spinach in pasteurized soil and in soil infested by *P. ultimum* compared with curve representing ratio of growth rates of host and pathogen reproduced from figure *1,A*. Spinach escaped infection by *P. ultimum* at 4° C., where the host grew relatively faster than the pathogen, and was most severely infected between 12° and 20°, where the fungus grew relatively faster than the host.

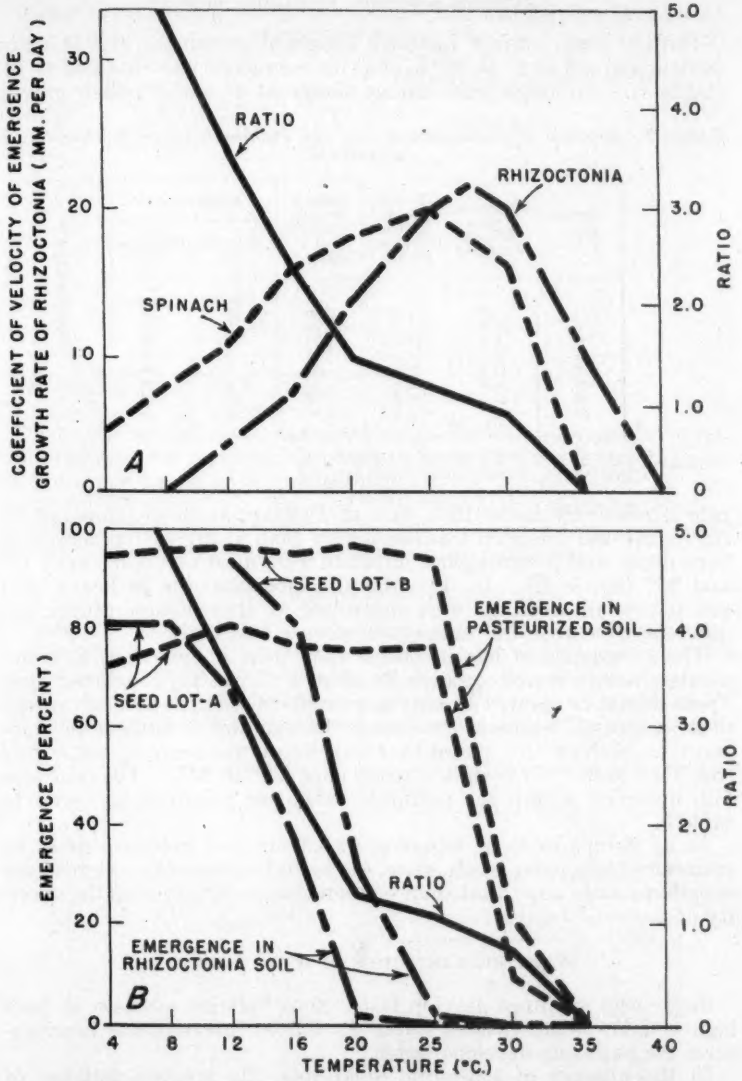

FIGURE 2.—*A*, Coefficient of velocity of emergence of spinach at temperatures of 4° to 40° C., growth rate of *Rhizoctonia solani* on agar, and ratio of emergence rate of spinach to growth rate of *Rhizoctonia*. The low temperatures were more favorable for the host and the high temperatures for the pathogen. *B*, Percent emergence of spinach in pasteurized and in *Rhizoctonia*-infested soil compared with curve representing ratio of growth rates of host and pathogen reproduced from figure 2,*A*.

PYTHIUM INFECTION OF GARDEN PEAS

Garden peas (variety Laxton's Progress) germinate well in moist pasteurized soil at 4° to 30° C., but no emergence was obtained at 35° (table 5). Although peas emerge slowly at 4° and 8°, their growth

TABLE 5.—*Relation of growth rates of peas and Pythium ultimum to emergence in infested soil*

Temperature (° C.)	Emergence of peas, coefficient of velocity	Growth rate of *P. ultimum* milligrams per day	Ratio of growth rates,[1] host to pathogen	Emergence in—	
				Pythium soil	Pasteurized soil
				Percent	*Percent*
4	2.4	1.0	2.40	66	89
8	4.6	3.6	1.28	18	90
12	8.8	12.2	.72	2	98
16	10.5	17.2	.61	0	93
20	12.3	22.2	.55	0	93
25	16.8	19.4	.86	2	94
30	15.1	15.6	.97	32	86
35	0	8.0	——	0	0

[1] Ratio = $\frac{\text{Emergence rate of peas (coefficient of velocity)}}{\text{Growth rate of } P.\ ultimum \text{ (milligrams per day)}}$.

rate is relatively faster than that of *Pythium* at these temperatures (fig. 3, *A*) and infection was less severe than at higher temperatures. Seed decay and preemergence infection were most severe between 12° and 25° (fig. 3, *B*). In this trial the inoculum was so heavy that practically all seedlings were destroyed at these temperatures and differences between the temperatures were obscured.

The occurrence of less infection upon peas at low than at intermediate temperatures confirms Reinking's (*19, p. 41*) conclusion that "peas should be planted as early as possible in order to take advantage of the cooler soil temperatures that are unfavorable to fungous development." McNew (*16*) stated that seed decay was more severe in cool soils (15° to 20° C.) than in warmer ones (29° to 32°). His cool soils fall, however, within the optimum range for infection as shown in table 5.

In all comparisons of temperature effects, soil moisture must be maintained at similar levels, since, as shown by Jones (*8*), soil moisture is perhaps more important than temperature in determining the severity of pea seed decay.

PYTHIUM INFECTION OF SUGAR BEET

Sugar beet seedlings develop faster than *Pythium ultimum* at both high and low temperatures (table 6), but at intermediate temperatures the pathogen develops faster.

In the absence of soil-borne organisms, the greatest number of sugar-beet seedlings was produced at 12° to 30° C., somewhat fewer at 4° and 8°. A temperature of 35°, however, not only reduced the number but resulted in the production of weak seedlings. In *Pythium*-infested soil, preemergence damping-off was most severe at 12° to 20°, where the ratio of the growth rate of the host (table 6) to that of the pathogen was the lowest.

TABLE 6.—*Relation of growth rates of sugar beets and Pythium ultimum to emergence in infested soil*

Temperature (° C.)	Emergence of sugar beets, coefficient of velocity	Growth rate of *P. ultimum*	Ratio of growth rates,[1] host to pathogen	Emergence of seedlings per 100 seed balls in—			
				Pythium soil			Pasteurized soil
				Trial A	Trial B	Trial C	
		Milligrams per day		*No.*	*No.*	*No.*	*No.*
4	1.6	1.0	1.60	54	70	46	114
8	4.6	3.6	1.28	32	18	28	145
12	8.4	12.2	.69	1	0	15	186
16	10.8	17.2	.63	0	0	15	189
20	16.1	22.2	.72	0	0	12	193
25	23.4	19.4	1.21	5	2	38	209
30	23.8	15.6	1.52	49	30	132	192
35	21.9	8.0	2.74	109	141	90	75

[1] Ratio = $\frac{\text{Emergence of beets (coefficient of velocity)}}{\text{Growth rate of } P.\ ultimum \text{ (milligrams per day)}}$.

Since the zone of severe infection coincides with the most favorable temperatures for germination of sugar beets (fig. 4, *A*) and since infection may be fairly severe throughout the normal range for germination (8° to 30° C.) (fig. 4, *B*), there is little possibility of eliminating *Pythium* infection by altering the planting date as long as soil moisture conditions remain favorable for the pathogen.

RHIZOCTONIA INFECTION OF SUGAR BEET

When the growth rates of sugar beets and *Rhizoctonia solani* (table 7) are compared, low temperatures seem to be much more favorable to the host than to the pathogen (fig. 5, *A*). In soil of moderate infestation (trial A), preemergence damping-off was most severe at 20° to 30° C., corresponding to the lowest ratios of the emergence rate

TABLE 7.—*Relation of growth rates of sugar beets and Rhizoctonia solani to emergence in infested soil*

Temporary (°C.)	Emergence of sugar beets, coefficient of velocity	Growth rate of *R. solani*	Ratio of growth rates [1] host to pathogen	Emergence of—		
				Seedlings per 100 seed balls in—		
				Rhizoctonia soil		Pasteurized soil
				Trial A [2]	Trial B [3]	
		Millimeters per day		*Number*	*Number*	*Number*
4	1.6	0	∞	122	116	114
8	4.6	.1	46.00	199	143	145
12	8.4	3.1	2.71	128	183	186
16	10.8	6.9	1.56	83	3	189
20	16.1	13.4	1.20	23	0	193
25	23.4	19.0	1.23	73	0	209
30	23.8	19.7	1.21	147	4	192
35	21.9	9.7	2.26		53	75

[1] Ratio = $\frac{\text{Emergence of beets (coefficient of velocity)}}{\text{Growth rate of } F.\ solani \text{ (millimeters per day)}}$.
[2] Soil moderately infested.
[3] Soil heavily infested.

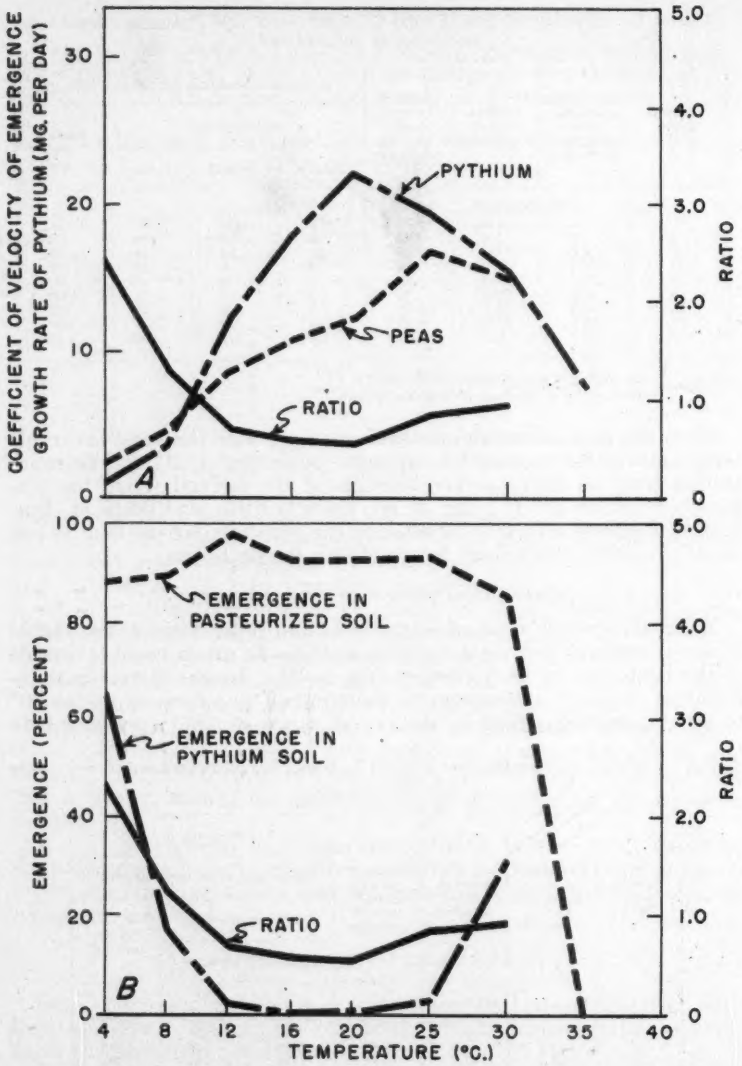

FIGURE 3.—*A*, Coefficient of velocity of emergence of garden peas, growth rate of *Pythium ultimum* in liquid medium, and ratio of emergence rate of peas to growth rate of *Pythium; B*, percent emergence of peas in pasteurized and in Pythium-infested soil compared with curve representing ratio of growth rates of host and pathogen reproduced from figure 3, *A*. Seed decay was less severe at high and low temperatures than between 12° and 25° C., a relation corresponding to the ratio between growth rates of host and pathogen.

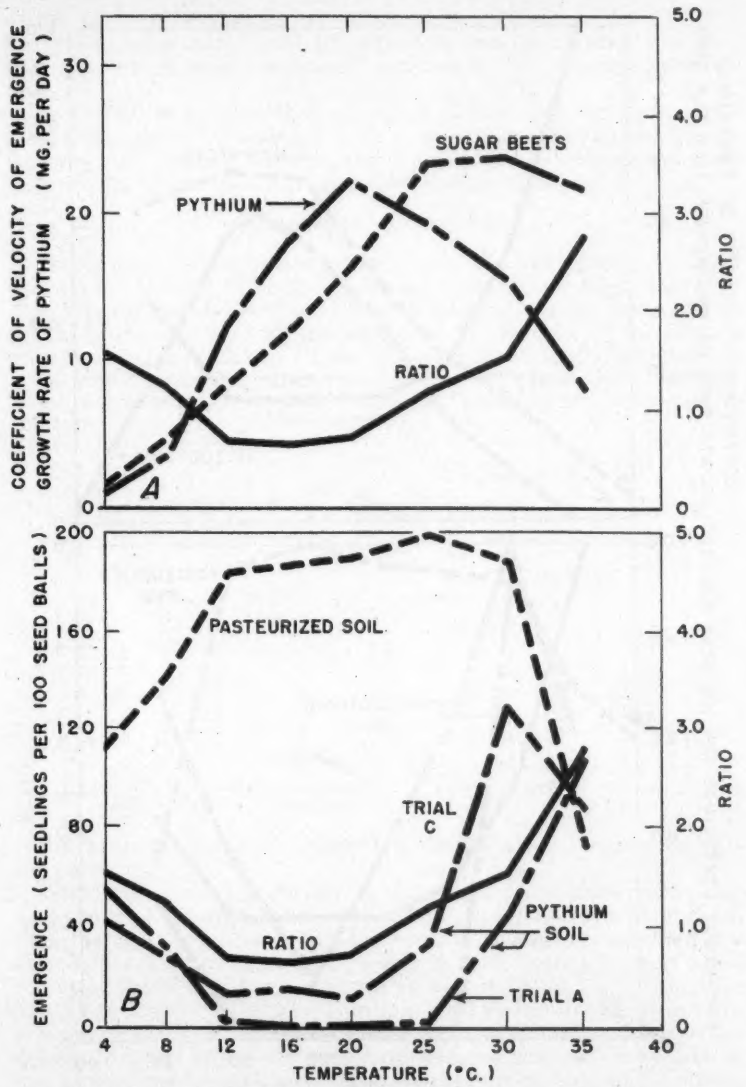

FIGURE 4.—*A*, Coefficient of velocity of emergence of sugar beets, growth rate of *Pythium ultimum* in liquid medium, and ratio of emergence rate of sugar beets to growth rate of *Pythium*; *B*, percent emergence of sugar beets in pasteurized soil and in soil infested by *P. ultimum* compared with curve representing ratio of growth rates of host and pathogen reproduced from figure 4, *A*. *Pythium* infection was severe throughout the temperature range favorable for germination of sugar beets.

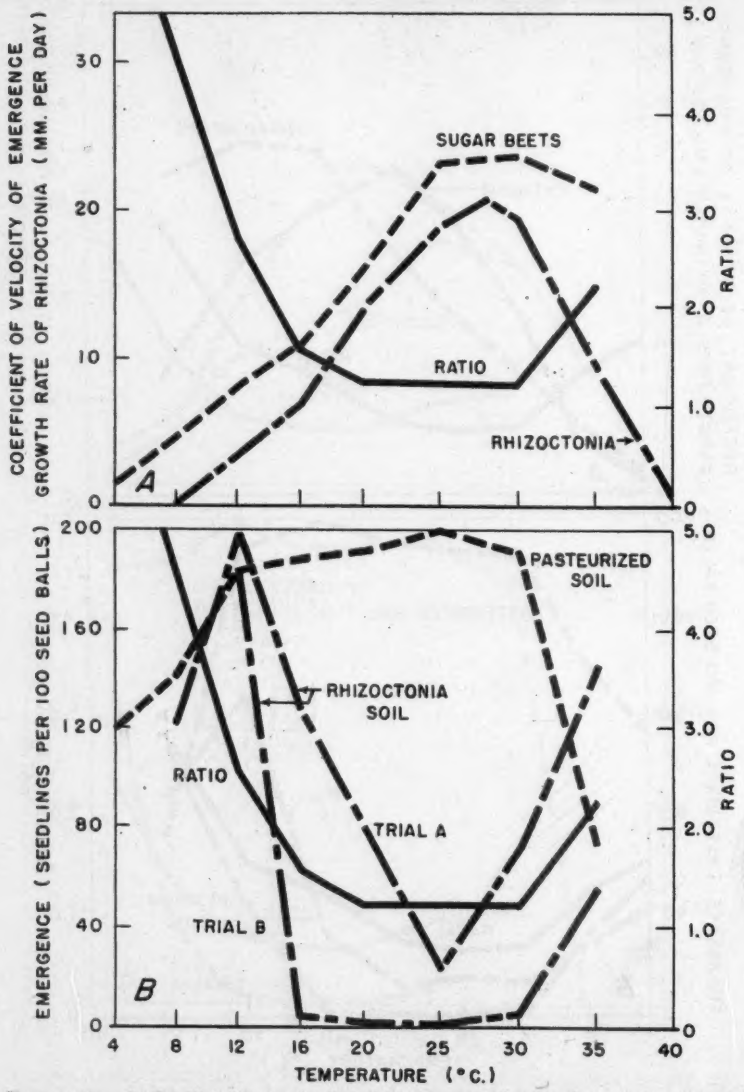

FIGURE 5.—*A*, Coefficient of velocity of emergence of sugar beets, growth rate of *Rhizoctonia* on agar, and ratio of emergence rate of sugar beets to growth rate of *Rhizoctonia*; *B*, percent emergence of sugar beets in pasteurized soil and in soil infested by *R. solani* compared with curve representing ratio of growth rates of host and pathogen reproduced from figure 5, *A*. Infection was severe between 16° and 30° C. with a maximum at 25°, near the optimum for both host and pathogen, but there was no infection at 12° or below where the host grew relatively faster than the fungus.

of the host to the growth rate of the pathogen (fig. 5, *B*). With a heavy soil infestation (trial B), infection was severe at 16° to 30°, but no preemergence damping-off occurred at 12° or below in either trial.

These results suggest that plantings at low temperatures would escape *Rhizoctonia* infection. Such a conclusion is supported by the fact that in central California this fungus is rarely recovered from early spring plantings but frequently from later ones.

PHOMA INFECTION OF SUGAR BEET

Phoma betae differs in one respect from the pathogens previously discussed. Instead of being soil-borne, it is carried either internally or externally on the beet seed balls produced in some areas. This fungus grows slowly at all temperatures, but a study of the relative growth of sugar beets and *Phoma* (table 8) shows that the higher the

TABLE 8.—*Relation of temperature to growth of Phoma betae and to emergence of Phoma-infected beet seed*

Temperature (°C.)	Emergence of beets, coefficient of velocity	Growth rate of *P. betae*,	Ratio of growth rates,[1] host to pathogen	Emergence in pasteurized soil of seedlings per 100 seed balls		
				Phoma-infected seed		Disease-free seed
				Lot A	Lot B	
		Milligrams per 24 hours		*Number*	*Number*	*Number*
4	1.6	0.7	2.28	3	------	114
8	4.6	1.3	3.54	9	38	145
12	8.4	2.4	3.50	41	91	186
16	10.8	3.0	3.60	45	102	189
20	16.1	4.3	3.74	77	139	193
25	23.4	4.7	4.98	129	144	209
30	23.8	3.6	6.61	131	132	192
35	21.9	.4	54.75	68	------	75

[1] Ratio = $\frac{\text{Emergence of beets (coefficient of velocity)}}{\text{Growth rate of } P.\ betae \text{ milligrams per day)}}$.

temperature the more favorable it is for the host as compared with the pathogen.

With most seed lots *Phoma* produces chiefly postemergence root or hypocotyl infection and little or no preemergence damping-off. In a few heavily infected lots, however, preemergence infection was abundant. Two of these lots, A and B, were tested in pasteurized soil at 4° to 35° C. Each emerged as well at 25° or 30° as when the lots were disinfected before planting; but at low temperatures the emergence of *Phoma*-infected lots dropped much lower than that of disease-free seed lots at the same temperatures. As shown by table 8, the zone of severe preemergence infection corresponds to the lowest ratios between host growth rate and pathogen growth rate.

Low emergence of both infected and disease-free seed lots at 35° C. is characteristic of all plantings at that temperature.

PHYTHIUM INFECTION OF WATERMELON

In contrast to spinach and peas, watermelon is typical of high-temperature crops. Even in pasteurized soil (table 9) no seedlings emerged at 12° C. or below, only a few appeared at 16°, but excellent results were obtained at 20° to 35°. The highest emergence rate was found at 35°, with the rate decreasing as the temperature was lowered (fig. 6, *A*). The ratio of growth rates shows that at low temperatures *Pythium* grew relatively faster than watermelon, whereas at high temperatures this relation was reversed.

TABLE 9.—*Relation of growth rates of watermelon and Pythium ultimum to emergence in infested soil*

Temperature (° C.)	Emergence of watermelon, coefficient of velocity	Growth rate of *P. ultimum*,	Ratio of growth rates,[1] host to pathogen	Emergence in—			
				Pythium soil			Pasteurized soil
				Trial A [2]	Trial B [3]	Trial C [3]	
		Milligrams per day		*Percent*	*Percent*	*Percent*	*Percent*
4	0	1.0	0	--------	--------	--------	--------
8	0	3.6	0	--------	--------	--------	--------
12	0	12.2	0	0	0	0	0
16	3.6	17.2	.21	0	0	0	17
20	8.5	22.2	.38	20	0	1	94
25	21.1	19.4	1.09	64	1	6	90
30	28.7	15.6	1.84	73	19	8	92
35	33.0	8.0	4.12	98	91	[4] 75	96

[1] Ratio = $\frac{\text{Emergence of watermelon (coefficient of velocity)}}{\text{Growth rate of } P.\ ultimum \text{ (milligrams per day)}}$

[2] Moderately infested soil.

[3] Heavily infested soil.

[4] 33° C.

By comparing the emergence in pasteurized soil with that in moderately infested soil (trial A), one can see that preemergence infection was severe at 16° and 20° C., moderate at 25° and 30°, and totally absent at 35° (fig. 6, *B*). In heavily infested soil (trials B and C) severe preemergence infection occurred at temperatures as high as 30° but not at 35°. The unintentional lowering of the temperature from 35° to 33° resulted in some preemergence infection in trial C.

The severity of infection in each trial was closely related to the ratio of growth rates at that temperature (fig. 6, *B*).

These data strikingly resemble Arndt's results (*1*) with cotton seedlings in *Pythium*-infested soil. Comparison of Arndt's "time required for emergence" for cotton with the present data on the growth rate of *P. ultimum* (table 2) indicates that his ratios would be similar to those for watermelon and *Pythium* at the same temperature. Arndt's findings could therefore be explained on the same basis.

RHIZOCTONIA INFECTION OF WATERMELON

Although *Rhizoctonia solani* does not grow so well at low temperatures as *Pythium ultimum*, its growth rate exceeds that of watermelon seedlings below 25° C. Above that temperature, conditions are increasingly favorable to watermelon. A single trial in heavily

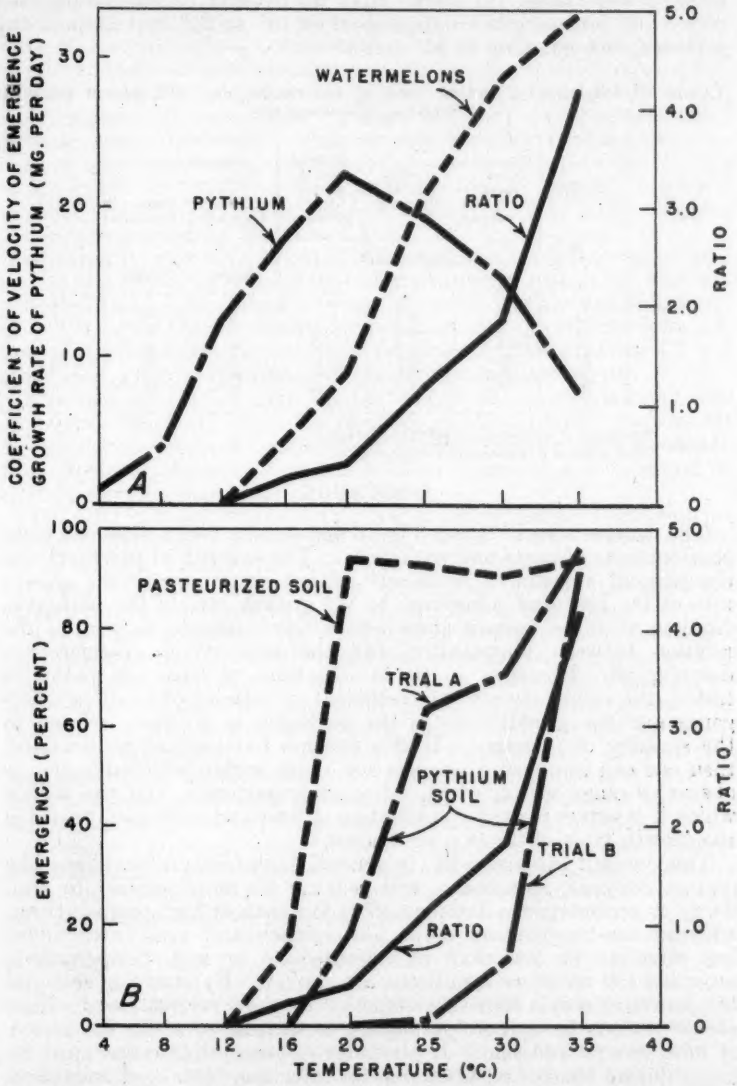

FIGURE 6.—*A*, Coefficient of velocity of emergence of a high temperature crop, watermelon; growth rate of a low temperature fungus, *Pythium ultimum;* and, ratio of the emergence rate of watermelon to growth rate of *Pythium*. *B*, Percent emergence of watermelon in pasteurized soil and in soil infested by *P. ultimum* compared with curve representing ratio of growth rates of host and pathogen reproduced from figure 6, *A*. Low temperatures favored the growth of the pathogen whereas high temperatures favored that of the host; damping-off decreased as the temperature rose.

infested soil (table 10) shows that *Rhizoctonia* causes severe seed decay and preemergence damping-off at 16° to 25°, but little if any preemergence infection at 30° and 35°.

TABLE 10.—*Relation of growth rates of watermelon and Rhizoctonia solani to emergence in infested soil*

Temperature (°C.)	Emergence of watermelon, coefficient of velocity	Growth rate of *R. solani*,	Ratio of growth rates [1] host to pathogen	Emergence in—	
				Rhizoctonia soil	Pasteurized soil
		Millimeters per day		*Percent*	*Percent*
4	0	0	----	----	----
8	0	.1	0	----	----
12	0	3.1	0	0	0
16	3.6	6.9	.52	0	17
20	8.5	13.4	.63	0	94
25	21.1	19.0	1.11	0	90
30	28.7	19.6	1.46	83	92
35	33.0	9.7	3.40	90	96

[1] Ratio = $\frac{\text{Emergence of watermelon (coefficient of velocity)}}{\text{Growth rate of } R.\ solani \text{ (millimeters per day)}}$.

DISCUSSION

The comparisons in tables 3 to 10 and figures 1 to 6 illustrate eight combinations of hosts and pathogens. The severity of preemergence damping-off appears to be closely related sometimes to the growth rate of the host and sometimes to the growth rate of the pathogen. Neither of these factors alone adequately explains, as a rule, the relation between temperature and the severity of preemergence damping-off. However, in all combinations of host and pathogen tested, the ratio between the coefficient of velocity of seedling emergence and the growth rate of the pathogen is inversely related to the severity of infection. If this relation has general applications, then one can establish a temperature range within which infection is absent, a range within which infection is moderate, and one within which it is severe for any combination of host and pathogen, provided the growth rates of the two are known.

This concept explains why, in general, high-temperature crops like cotton, cowpeas, lima beans, and peanuts are more subject to seed decay or preemergence damping-off at low than at high temperatures, whereas low-temperature crops like spinach and peas often suffer less infection at low than at intermediate or high temperatures, provided soil moisture conditions are similar. By studying seasonal temperatures one is sometimes enabled to plant certain crops within escape periods for specific pathogens, or at least to avoid the period of most severe infection. If plantings of susceptible crops must be made during the period favorable for infection, then seed treatment is imperative; and one should select the specific treatment most effective against the organism or organisms most likely to operate at a given soil temperature.

In all combinations of host and pathogen, the lower the ratio of the growth rates, the more severe was the preemergence damping-off. For example, with sugar beets a rapid-growing fungus such as *Pythium*

ultimum shows a growth-rate ratio below 1.0 and causes severe preemergence infection at temperatures favorable to the fungus. With *Rhizoctonia solani*, a somewhat slower-growing fungus, the ratio of growth rates at temperatures most favorable to the fungus is between 1.0 and 2.0. At these temperatures *Rhizoctonia* produces less preemergence infection than *Pythium* but may cause considerable postemergence infection. With a slow-growing fungus, such as *Aphanomyces cochlioides*, sugar beets show a growth-rate ratio of 2.5 to 3.2 at the temperatures most favorable for the fungus. Infection by this organism is limited almost entirely to the postemergence phase, as reported by Buchholtz (*2*).

Apparently, therefore, ratios of below 1.0, indicating that the growth rate of the pathogen exceeds that of the host, are associated with the potentiality of severe preemergence infection. As the ratios increase from 1.0 to 4.0 the probability of preemergence infection is lessened, but postemergence infection may be severe. Ratios above 4.0 are associated with total absence of preemergence damping-off.

The present studies were limited chiefly to observations on preemergence infection, since the methods employed were not suitable for testing the effect of temperature on postemergence phases. Probably, however, the same relations hold for many types of infection on rapidly growing plant parts.

The occurrence of strains of a pathogen having different temperature requirements would alter these relations; and, when tested on the same hosts, a low-temperature strain of *Rhizoctonia solani* such as reported by Kadow and Anderson (*10*) would probaby not show the same temperature relations as the strain used in these trials.

The similarity between the ratio of growth rates and the severity of infection does not necessarily mean that growth rate is the controlling factor. In specific cases the susceptibility of seedlings has been shown to be correlated with chemical differences in the host brought about by temperature, as reported by Dickson and Holbert (*4*) and by Reddy (*18*). Investigations by McClure and Robbins (*15*) showed that resitance of cucumber seedlings to postemergence infection by *Pythium* was associated with cell-wall lignification, which in turn was influenced by age of seedlings, nitrogen nutrition, and light.

Probably, however, even in these cases, the physiological or anatomical changes in the host that limit infection are closely associated with the growth rate of the host and infection is related to the relative activity of the host and the pathogen.

SUMMARY

To determine the effect of temperature upon the severity of preemergence damping-off, spinach, sugar beets, peas, and watermelons were germinated in pasteurized soil and in soil infested by specific pathogens and maintained at controlled soil moistures and temperatures.

The coefficient of velocity of emergence was determined for each host from daily emergence counts in pasteurized soil at each temperature. The growth rate for each pathogen was determined at each temperature from measurements on agar plates or from nutrient solutions.

Spinach, a low temperature crop, was most severely infected in *Pythium*-infested soil between 12° and 20° C. and escaped preemerg-

ence infection only at 4°. In *Rhizoctonia*-infested soil, however, spinach suffered little or no preemergence infection at 12° or below, moderate infection at 16°, and severe preemergence damping-off at 20° or above.

Watermelon, a high temperature crop, escaped infection by either *Pythium* or *Rhizoctonia* at 35° C. but was more severely infected as the temperature was lowered.

In *Pythium*-infested soil, seed decay and preemergence infection of garden peas was most severe between 12° and 25° C.

The temperature ranges in which the most severe preemergence infection of sugar beets occurred were: *Pythium*-infested soil, 12° to 20° C.; *Rhizoctonia*, 16° to 30°; and from seed infected with *Phoma betae*, 4° to 20°.

In all combinations of host and pathogen preemergence infection was most severe at temperatures that were relatively less favorable to the host than to the pathogen as measured by the ratio of their growth rates.

From these trials it appears, therefore, that other factors being constant, the relative growth rates of the host and pathogen determine to a considerable degree the severity of preemergence infection at different temperatures.

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RESISTANCE OF LATHYRUS SPP. AND PISUM SPP. TO ASCOCHYTA PINODELLA AND MYCOSPHAERELLA PINODES [1]

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INTRODUCTION

The culture of the Austrian Winter field pea, a variety of *Pisum sativum* L., grown as a winter cover crop throughout the southeastern part of the United States and the Pacific Northwest, is considerably restricted by its susceptibility to diseases. Most destructive of these diseases in the Southeast are those caused by *Ascochyta pinodella* L. K. Jones, *Mycosphaerella pinodes* (Berk. and Blox.) Vest., and *Aphanomyces euteiches* Drechs. In the hope of discovering for use in breeding work a field pea more resistant than the Austrian Winter variety to these fungi a study was initiated in the autumn of 1935 at Experiment, Ga. During a 10-year period many different lots of *Pisum* and a few of *Lathyrus* were tested, many of them several times. Some of the difficulties involved and the methods of surmounting them were described in a preliminary report in 1940.[3] The present paper records the results of the studies of the species, varieties, and strains for resistance to *A. pinodella* and *M. pinodes* only. The investigations of *A. euteiches* are not entirely complete, and the results will be reported at some future date.

MATERIALS AND METHODS

The seeds used in these investigations were obtained in this country and from abroad. Few of the peas tested, other than the lots of the Austrian Winter variety, were able to survive the more severe of the winters at Experiment, Ga. It became necessary, therefore, to provide a measure of protection for the plants, especially during cold nights. Previously described hotbeds,[3] heated with electric cable and covered with heavy cloth, were found to be adequate. The seeds were planted during the first half of October in well-fertilized field soil in 6-inch pots. When available, 10 seeds were planted in each pot.

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[2] Grateful acknowledgment is made to Roland McKee, Division of Forage Crops and Diseases, to H. A. Schoth, Oregon State College, Corvallis, Oreg., and to the many others who supplied the seed used in these investigations.

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In order to insure abundant infection 2- to 4-inch plants were inoculated by placing on the surface of the soil 1 or 2 tablespoonfuls of autoclaved peas on which the fungus to be tested was growing. After the inoculum was applied, the pots were watered thoroughly and kept covered with the hotbed cloth for 2 days; this cover was wet down several times during that period.

Since 2 fungi (*Ascochyta pinodella* and *Mycosphaerella pinodes*) were involved, it was necessary to have 2 duplicate sets of pots, 1 set in each bed. Thus, in most experiments 40 plants were under test at the same time. When the results were not conclusive, the lots were included in the test the following year. Pots of the Austrian Winter variety, which was used as the control, were scattered throughout the beds.

Samples of seed were sometimes obtained after the general planting had been made. The plants from such seed often made poor growth until late spring. These small plants were almost always less severely diseased than those of the lots planted earlier.

In late spring, usually about the first of May, the best plants were taken from the hotbeds to a cloth enclosure,[5] and seeds were obtained from most of them. Seeds thus obtained were tested again in the hotbed the following season. The best plants were also used as parents in the breeding program.

When sufficient seeds were available, duplicate rod rows were planted in the field on land that had grown peas for two or more consecutive years. No attempt was made to inoculate the field-grown plants, and the amount of infection varied considerably from year to year, depending on the rainfall. In some years a large proportion of the plants growing in the field were killed by freezing and disease.

In addition to stand counts made in late autumn, notes were taken at irregular intervals, usually two or three times during the spring months. The final observations were made in late April or early May. The ratings made at this time were used as the best obtainable criterion of the resistance of the plants.

Hotbed space, seed, and labor were not available in sufficient quantity to permit the planting of enough replications to make a statistical study of the data worth while. The fact that the control pots in different parts of the same hotbed varied widely showed that a large number of replications would have been necessary to establish statistically significant differences. In view of these variations it was concluded that only the rating denoting the most severe infection could be accepted as indicative of the susceptibility of a variety. Often ratings were influenced by place effect, seasonal growth rate, and doubtless other factors not always recognized. When possible, doubtful ratings were checked in repeated hotbed tests as well as in field plots.

The plants were rated as follows: Immune, highly resistant, resistant, moderately resistant, susceptible, and very susceptible. No counts were made. The most important items considered in making the ratings were (1) killing of the plants, (2) extent of the damage to the lower part of the stem and percentage of stem involved, (3) num-

[5] See footnote 3, p. 181.

ber of basal leaves that had been killed, and (4) severity of spotting and amount of dead tissue in the upper leaves.

It was found that, even though the pots inoculated with the two fungi were kept in separate hotbeds, the distance between them was not sufficient to prevent the spread of the fungi from one bed to the other. Consequently there was a mixture of the two fungi in both beds, especially by late spring. Since the symptoms produced by the two fungi are so nearly alike, it was impractical to differentiate plants affected by them. Likewise, septoria leaf spot sometimes was prevalent early in the spring as a result of natural infection. It was impossible, therefore, to give to each lot of plants a rating that would denote its true reaction to either of the fungi tested. Such ratings, if desired, must be obtained by other experimental methods. The results presented in this paper must be considered as a composite reaction of the plants to inoculation with *Ascochyta pinodella* and *Mycosphaerella pinodes* and to a slight extent to natural infection with *Septoria pisi* West. Whenever possible, however, injury caused by *Septoria* was disregarded. From many viewpoints composite results of this nature are not the most desirable, but they represent exactly the condition found in the field. Since the objective of these tests was to find breeding stock that would survive this combination of diseases, the methods were considered suitable for the purpose.

SYMPTOMS USED IN RATING RESISTANCE

Although several thousand plants were inoculated and studied, there was not found any single symptom that would consistently differentiate the diseases caused by *Ascochyta pinodella* and *Mycosphaerella pinodes* under the conditions of these experiments. The only certain method of determining which fungus was present was to make isolations. The study of pycnidia often present on dead parts was also helpful. The symptom most commonly found early in the spring was a browning or blackening of the base of the stems, which usually started just below the surface of the soil. In very susceptible varieties the stem was decayed entirely through in a relatively short time and the plant died; in other varieties the damage was more superficial, and death came more slowly, if at all. Some plants tested were already killed, or nearly so, when the Austrian Winter plants showed almost no disease. There were all gradations between these extremes.

Another prominent symptom was leaf spot. Usually this did not develop in abundance until later in the spring, when it varied in severity, depending largely on weather conditions. The leaves were killed from the base of the plants upward. Sometimes 6 inches to 2 feet of the ends of the vines still had green leaves at the time the experiment was discontinued. In wet seasons all of the green leaves were more or less spotted, but when conditions were less favorable for infection some of the leaflets at the ends of the vines had few or no lesions.

The presence or absence of leaf spotting, especially late in the spring, was of doubtful value as an aid in rating the different lots. Many of the plants grew rapidly and produced long vines that climbed over the tops of the other plants or the sides of the bed where there were free air circulation and consequent rapid dissipation of rain and dew. Other plants grew slowly, and their tops always remained near the ground where the humidity was higher.

The spotting of pods was of no importance in this work, since the experiments were largely discontinued before pods were formed.

The plants of certain varieties grew rapidly throughout the season, whereas those of others grew slowly and made almost no growth during the colder winter months. In the former group were most of the English, or garden, peas (*Pisum sativum*); in the latter group were the more winter-hardy types such as the Austrian Winter peas. The diseases frequently appeared to make progress in proportion to the rate of growth of the plant, so that the stems of rapidly growing plants often quickly decayed and the plants were killed or nearly killed (fig. 1) at a time when the slower growing plants still remained

FIGURE 1.—Field pea plants from an inoculated imported lot of seed, typical of the rapid-growing type of plant, as they appeared on February 12, 1941. Practically all of the lower leaves had been killed, and large dark-brown lesions were present on the stems. All of the plants were dead on March 26. They were planted at the same time and treated the same as those shown in figures 2 and 3. × ½.

fairly free from disease (figs. 2 and 3). The slower growing lots in turn became severely diseased when they started rapid growth in the spring. The final result, insofar as the total amount of disease was concerned, was about the same by late spring, although some lots lived to produce much more green weight than others.

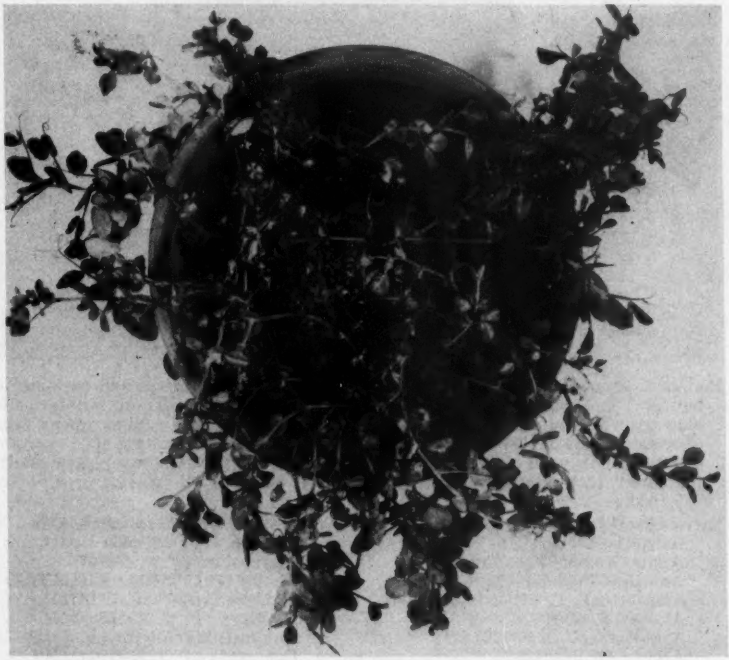

FIGURE 2.—Inoculated Austrian Winter field peas from a hotbed as they appeared on February 12, 1941. Some very small stem and leaf lesions caused by *Ascochyta pinodella* and *Mycosphaerella pinodes* were evident, and some of the lower leaflets had been killed by *Septoria pisi*. In general, however, the plants were still fairly healthy as compared with those shown in figure 1. × ½.

EXPERIMENTAL RESULTS

In some experiments a few isolated lots of *Pisum sativum* showed some resistance, but when retested they too were very susceptible to *Ascochyta pinodella* and *Mycosphaerella pinodes*. The named varieties and the unnamed strains of *Pisum sativum*, the unnamed strains of *Pisum* spp., and the lots of seed with numbers only that were rated as very susceptible follow.

Varieties of *Pisum sativum:*
- Admiral (F. C.[1] 29931)
- Advancer (F. C. 30049)
- Agnes No. 7 (F. C. 29911)
- Alah

Varieties of *Pisum sativum*—Con.
- Alaska (F. C. 29932)
- Alberta Blue (F. C. 29933)
- Alcross (F. C. 30051)
- Alderman (F. C. 30052)

[1] F. C. refers to accession numbers of Division of Forage Crops and Diseases.

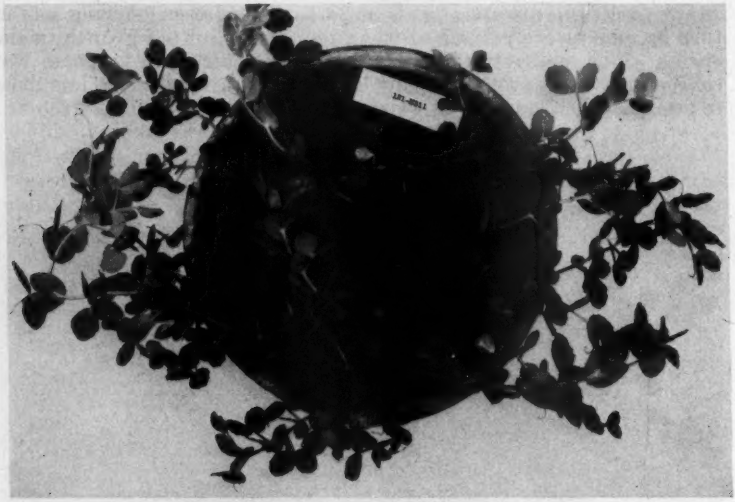

FIGURE 3.—Inoculated plants of a double cross from the same hotbed as those in figures 1 and 2 as they appeared on February 12, 1941. These plants made slow growth and remained healthy much longer than the rapid-growing type shown in figure 1. They had been rated as very highly resistant to *Ascochyta* and *Mycosphaerella* on January 31; but, like the Austrian Winter plants shown in figure 2, they were rated as very susceptible on April 28. × ½.

Varieties of *Pisum sativum*—Con.
- Alfred (F. C. 29934)
- Allan Canner (F. C. 30053)
- American Wonder (F. C. 30054)
- Amraoti (F. C. 29935)
- Andes (F. C. 29936)
- Arabelle (F. C. 30073)
- Archer (F. C. 29937)
- Arthur (F. C. 29938)
- Arthur 108 (F. C. 29939; F. C. 30055)
- Austrian Winter[2]
- Bangalia (F. C. 29940)
- Belgium Sugar (P. I.[3] 137124)
- Benah
- Black Eye (F. C. 29913)
- Black-eyed Marrowfat (F. C. 22431)
- Bliss Everbearing
- Blue Bantam (F. C. 30057)
- Blue Imperial (F. C. 29942)
- Blue Prussian (F. C. 29941; F. C. 30058)
- Bothnia (P. I. 137174)
- Brown Abyssinian
- Canadian Beauty (F. C. 29943; F. C. 29944)
- "Capucyners"

Varieties of *Pisum sativum*—Con.
- Carlton (F. C. 29945)
- Chancellor (F. C. 29946)
- Chang (F. C. 29914; F. C. 30059)
- Chinese Purple (P. I. 137118)
- Clamart (F. C. 29915)
- Colorado Marrowfat (F. C. 29947)
- Concordia (P. I. 137175)
- Cossacks (F. C. 29948)
- Creole
- Cudoiz
- Daniel O'Rourke (F. C. 29949)
- Dashaway (F. C. 30060)
- Delano (F. C. 29950)
- Desi (F. C. 29951)
- Dwarf Telah
- Earliest Perfection (F. C. 30063)
- Early Britain (F. C. 29952)
- Early Briton (F. C. 30061)
- Early Perfectah
- Early Perfection
- Early Sabljas
- Early Washington (F. C. 30062)
- Early White (F. C. 29953)
- Express
- Farnham (F. C. 29956)
- First and Best (F. C. 29957)
- French Gray (F. C. 29916)

[2] 78 lots from different sources.
[3] P. I. refers to accession numbers of Division of Plant Exploration and Introduction.

Varieties of *Pisum sativum*—Con.
French June (F. C. 29958)
Friale (F. C. 29959)
Giant Edible Pod
Golden Marrow (F. C. 29917)
Golden Marrowfat (F. C. 30065)
Golden Vine (F. C. 22429)
Gradah
Gradus (F. C. 30066)
Green (F. C. 29961)
Green Scotch (F. C. 30067)
Greenville Nitrogen (F. C. 19003)
Gregory (F. C. 29962)
Grey Winter (F. C. 29963)
Gyllen (P. I. 137176)
Hanford's Canner (F. C. 30068)
Hangchow (F. C. 29964)
Harrison Glory (F. C. 30069)
Hawley's Improved (F. C. 30070)
Hero (P. I. 137177)
Home Delight
Horal (F. C. 30071)
Horsford Market Garden (F. C. 30072)
Hundredfold
Kaiser (F. C. 29970; F. C. 30074)
Killarney (F. C. 29969)
Kron (P. I. 137178)
Laxton Progress
Lima (F. C. 29918)
Lincoln (F. C. 31015)
Little Gem (F. C. 30075)
Little Marvel (F. C. 30076; F. C. 30077)
MacKay (F. C. 29971)
Maple Pea (F. C. 29922; F. C. 29920)
Marchioness (F. C. 29972)
Marcrosse (F. C. 29973)
Marrow
Marscot (F. C. 29974)
Marvel
Mash (F. C. 29975)
May
McAdoo
McKay Blackeye (F. C. 22430)
Merhaim
Meyer (F. C. 29976)
Minn. No. 95 (F. C. 29977)
Multiplier (F. C. 29978; F. C. 29979)
Nelson (F. C. 29980)
Ne Plus Ultra (F. C. 30080)
New Canadian Beauty (F. C. 29919)
New Perfection (F. C. 29981)
Nott's Excelsior (F. C. 30079)
Openshaw (F. C. 29982)
Ostgota Green (P. I. 137180)
Ostgota Yellow (P. I. 137181)
Ottawa (F. C. 30082)
Papago Indian Pea
Paragon (F. C. 29983)
Partridge (F. C. 29984)
Peluskchka (F. C. 29985)

Varieties of *Pisum sativum*—Con.
Pelusker (P. I. 137182)
Potter (F. C. 29986)
Premah
Premium Gem (F. C. 30086)
Prince of Wales (F. C. 30087)
Profusion (F. C. 30084)
Recordah
Red Pea
Rice Extra Early (F. C. 30090)
Rice No. 13 (F. C. 30088)
Rice No. 300 (F. C. 30089)
Rogers K
Sabljas
Sacton Progress (F. C. 30092)
Sand Pea (F. C. 93979)
Sato (F. C. 30091)
Scarlet
Scotch (F. C. 29987; F. C. 29988)
Scotch Blue (F. C. 29989)
Senator (F. C. 30093)
Shanghi (F. C. 29990)
Smiley (F. C. 29991)
Solo (P. I. 137183)
Stratagem (F. C. 30094)
Sugar Edible Podded
Sunrise (F. C. 30095)
Surprise (F. C. 30096)
Sweet Field Pea
Tall Grey Sugar (F. C. 30097)
Tall Telephone (F. C. 30098)
Telefon
Thracian Field Pea
Tom Thumb (F. C. 30099)
Torsdag II (P. I. 137184)
Victoria (F. C. 29993)
Vida (F. C. 29994)
V's No. 2 (F. C. 29995)
Walah
Warshauer (F. C. 29996)
Wellwood (F. C. 29997)
White Australian (F. C. 29998)
White Canada (F. C. 22424; F. C. 29999)
Willett's Wonder
Windsor (P. I. 137121)
Wisconsin Early Sweet (F. C. 30103)
Wisconsin Perfection (F. C. 30105)
Wisconsin Perien (F. C. 30104)
World's Pride (F. C. 30000)
Wyoming Wonder (F. C. 30106)
Yellow Admiral (F. C. 30001)
Unnamed strains of *P. sativum:*
A–15 (Iraq)
A–16 (China)
F. C. 30002
F. C. 30003
F. C. 30004
F. C. 30005
F. C. 30107
F. C. 30108
F. C. 30129
F. C. 30130

Unnamed strains of *P. sativum*—Con.
F. C. 30131
F. C. 30640
F. C. 30641
F. C. 30642
F. C. 30859
F. C. 31499
P. I. 19710
P. I. 24262
P. I. 92108
P. I. 125672
P. I. 125673
P. I. 125839
P. I. 125840
P. I. 131883
P. I. 131884
P. I. 134271
P. I. 134646
P. I. 135920
P. I. 137120
P. I. 137122
P. I. 137125
P. I. 138945
Wade's N802–2–1
Soil Conservation Service No. 20–489

Unnamed strains of *Pisum* spp.:
F. C. 30193
P. I. 126341
P. I. 141896
Lots of seed with numbers only:[4]
F. C. 60581
F. C. 60583
F. C. 60888
F. C. 60890
F. C. 60901
F. C. 60904
F. C. 60905
F. C. 60915
F. C. 60922
F. C. 60962
F. C. 61751
F. C. 62439
F. C. 87979
F. C. 87980
F. C. 87983
F. C. 90472
F. C. 90474
F. C. 90759
F. C. 91192
F. C. 93978

[4] 20 unnamed, unnumbered lots from different sources also tested.

Three lots of *Pisum elatius* Stev. (P. I. 120622, P. I. 120629, and P. I. 141891) were slightly resistant in the early stages of growth. The same was true of a wild species of *Pisum* from Turkey (probably also *P. elatius*, F. C. 30199). *Lathyrus tingitanus* L. was moderately resistant, *L. sativus* L. resistant, and *L. hirsutus* L. immune.

The fact that the strains of *Pisum elatius* were of the slow-growing type may partly explain their seeming resistance early in the season. Some plants of this species have been used in breeding experiments, and their progenies were tested over a period of several years. At present there is little evidence to support a conclusion that hybrids having *P. elatius* genes are any more resistant to *Ascochyta pinodella* and *Mycosphaerella pinodes* than others without them. In the present work it was necessary to obtain winter hardiness in a hybrid before it could be tested under field conditions. In order to breed winter hardiness into a line having *P. elatius* genes it was necessary to cross it and then backcross it with a winter-hardy variety. Even in such a cross a large proportion of the progeny was lost from freezing. In view of this complicating factor it may be desirable to explore the possibility of using this species as a source of germ plasm under other conditions.

There is real resistance in the genus *Lathyrus*, but all attempts to cross *Lathyrus* spp. with the Austrian Winter pea have failed.

DISCUSSION

It should be emphasized that the objective of the present study was to find a pea that is more resistant than the Austrian Winter to *Ascochyta pinodella* and *Mycosphaerella pinodes*. Whether it would have been practical, or for the present purpose desirable, to devise some method that might have made it possible to detect smaller differences in resistance, if such exist, may be debatable. Certainly considerable

difference in resistance was evident early in the course of the experiments; some plants were killed before others, such as the Austrian Winter and some of the new lines developed by breeding, had suffered any appreciable damage. These seemingly more resistant types, however, gradually succumbed as the season advanced, so that for the purpose of the present study there seemed to be little point in attempting to record these early differences.

It is true that the methods used put the plants to a very severe test, because the time over which the plants were exposed to the action of the fungi was very long, namely about 6 or 7 months as compared with about 2½ months required for many of the summer-grown garden and canning peas to complete their life cycle. The types of pea that remained dormant or grew more slowly during the winter months suffered little from disease during that period, whereas those that grew more or less all winter were correspondingly more severely injured by the fungi early in the season.

In general the writer's results agree with those of other workers. Seal [6] stated that he and Albrecht made a systematic search for species, subspecies, and varieties of *Pisum* and tested them for resistance to *Mycosphaerella pinodes*. So far as they could determine there was no marked difference in resistance to the fungi tested. After spending several years trying to develop a winter-hardy pea resistant to *Ascochyta pinodella* and *M. pinodes*, Ogden [7] concluded that he had found no strain resistant to these fungi. Noll [8] found that field peas (*P. arvense*) are more resistant to *A. pinodella* than are garden peas (*P. sativum*). Hare and Walker [9] tested 100 strains and varieties of *P. sativum* and concluded that no indication of practical tolerance to the ascochyta blight was found. Jones [10] tested the resistance of a large number of varieties of garden peas to *A. pinodella*, *A. pisi*, and *M. pinodes*. He found no varieties immune from any of these fungi but listed the Admiral 17.78, Advancer, Badger Special, Badger 20.140, Champion of England, Horsford, and Perfection as only slightly susceptible to *M. pinodes* and *A. pisi*. The Horsford Market Garden was the most resistant to all three of these fungi.

Ascochyta pisi, as well as *A. pinodella* and *Mycosphaerella pinodes*, produces ascochyta blight of *Pisum* spp. Since the Austrian Winter variety appears to be highly resistant to *A. pisi*, however, this fungus was not used in the present studies. Although it did produce a few lesions on the leaves of susceptible varieties as a result of natural infection, these lesions were never numerous enough to interfere with

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[6] SEAL, J. L. THE MYCOSPHAERELLA DISEASE OF WINTER PEAS, AND DISEASES OF WINTER PEAS AND VETCHES CAUSED BY ASCOCHYTA SPECIES. Ala. Agr. Expt. Sta. Ann. Rpt. (1937) 48: 24–25. [1938.]

[7] OGDEN, H. P. WINTER PEA BREEDING. Tenn. Agr. Expt. Sta. Ann. Rpt. (1935) 48: 11–12. [1936.]

[8] NOLL, W. ÜBER WEITERE BEFALLSYMPTOME UND MASSNAHMEN ZUR VERHÜTUNG VON SCHÄDEN DURCH ASCOCHYTA PINODELLA JONES, A. PISI LIB. UND MYCOSPHAERELLA PINODES (BERK. U. BLOX.) STONE BEI ERBSEN. Ztschr. f. Pflanzenkrank. 50: [49]–71, illus. 1940.

[9] HARE, W. W., and WALKER, J. C. ASCOCHYTA DISEASES OF CANNING PEA. Wis. Agr. Expt. Sta. Res. Bul. 150, 31 pp., illus. 1944.

[10] JONES, L. K. STUDIES OF THE NATURE AND CONTROL OF BLIGHT, LEAF AND POD SPOT, AND FOOTROT OF PEAS CAUSED BY SPECIES OF ASCOCHYTA. N. Y. State Agr. Expt. Sta. Bul. 547, 46 pp., illus. 1927.

note taking. Not all of the varieties listed as resistant to ascochyta blight by some writers were tested in the present investigations. It seems probable that such varieties as were tested failed to show resistance because of the severity of the method used and the long period over which the plants were exposed to the ravages of the disease.

SUMMARY

The results of 10 years of testing various varieties and strains of field and garden peas (*Pisum sativum*) have failed to disclose the existence of a pea that possesses any appreciably greater degree of resistance to *Ascochyta pinodella* or *Mycosphaerella pinodes* than does the Austrian Winter under the conditions of the experiments. Over 160 named varieties and many numbered and unnamed lots, some from several different sources, were studied. *Pisum elatius* and a wild pea from Turkey (probably *P. elatius* or a close relative) appeared to possess some resistance under the conditions of the experiments. Whether this was due to a transmissible character seems doubtful, since progeny from crosses in which these peas were used as a parent failed to show much if any increased resistance.

The strain of *Lathyrus hirsutus* used proved to be immune from the fungi studied, that of *L. sativus* was resistant, and that of *L. tingitanus* was moderately resistant. All attempts to cross these species of *Lathyrus* with the Austrian Winter pea failed.

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